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PROBLEMS AND STRATEGY OF THE FIRST FLIGHT TO THE COMETS

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## PROBLEMS AND STRATEGY OF THE FIRST FLIGHT TO THE COMETS

By V. D. Davydov

### The Least Type of Studied Objects in the Solar System

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Comets are studied each time they appear, but despite the use of large telescopes and the most advanced instruments from the arsenal of modern ground-based astronomy, these amazing celestial bodies are the least understood of all the objects in the solar system. Very bright comets appear fairly rarely: 2-3 times in a century. The possibilities of remote study of the most frequently observed "small" comets that pass a distance on the order of hundreds of millions of kilometers and more from the Earth are restricted under conditions of ground-base observatories by the parameters of the optic instruments and interferences of the earth's atmosphere to an even greater measure than the bright comets.

The information on the composition of the comet substance is based on an interpretation of the spectra of luminous diffused parts of the comet: head and tail in the form of one or several tails. In both the heads and the tails of the comets one observes not the original substance that evaporates from the nucleus under the rays of the sun, but the product of breakdown and ionization of molecules under conditions of the interplanetary medium under the influence of ultraviolet

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\*Numbers in margin indicate pagination in original foreign text.

rays and during the interaction with the solar wind. Thus, we do not have any direct data on the molecular and mineral composition of the nucleus where the main mass of the comet substance is concentrated.

The nature of the comet nuclei remains very enigmatic. Currently, we know absolutely nothing about the structure and mass of the nucleus of any comets, not to mention the range of differences in the characteristics of different comets. At the same time, information has been discovered in the structure and properties of the comet nuclei on questions that are inseparably linked to the main problems of cosmogony of the solar system.

The ideas on how and from where new comets could emerge are still far from /4 complete clarity; only the main strokes of a possible picture in different variants are being outlined. The proponents of the Soviet cosmogenic school, founded by O. Yu. Shmidt, assume that comets could be formed in the process of formation of giant planets, that by the gravity effect scooped out some condensations of substance and ejected other condensations from the peripheral regions of the protoplanetary cloud. In such a case the age of the comets must number over 4 billion years. On the other hand, a considerable diminishing has been noted in the activity of the short-periodic comets with subsequent returns to the perihelion, and even complete destruction during the observation periods, seven orders younger than the indicated age. Attempts have been made to explain the possibility of preservation of the comet nuclei during the previous epochs in combination with the rapid evolution of the observed comets in the framework of a "comet cloud" model with radius on the order  $10^5$  astronomical units; the idea of its existence was developed by Oort and his followers. Good critical surveys that supplement each other on this question and a bibliography can be found in the following publications [1, 2, 3].

Academician V. G. Fesenkoy, in analyzing the data on comet structure has written that the comet nuclei can hardly represent solid monolithic bodies, or a cluster of particles that are not at all interlinked, but apparently are weakly linked structures [3]. Observations have been made repeatedly of phenomena of breakdown of a certain comet into individual parts, and the formation of a cluster of small bodies that are stretched in a broad stream along the comet orbit (meteor stream).

After the publication of the cited work breakdown of the comet Vest was observed; it passed the perihelion on 25 February 1976 a distance of 0.197 a. u. from the sun. Near the perihelion it broke down into parts [4]; in the beginning of March one could observe three nuclei that gradually separated from each other, and gradually attenuating in luster, they were recorded and photographed up to September. /5

According to modern concepts, the activity of comet nuclei and the set of emissions in the spectra of comets could be explained by assuming that the comet nuclei composition contains solid substances that are easily evaporated during heating, for example, ices of hydrocarbon compounds and  $H_2O$ . But the comets contain more than these. In the spectra of the comet tails of a certain type (such tails were not observed in all the comets) there is a scattered solar light. Apparently stony particles, since in the case of exceptionally close convergence of the comet to the sun emission lines of many metals appear in the spectrum. Consequently, in addition to the escape of gaseous products, stony particles are discharged from the comet nuclei. The discharges occur continuously (but not uniformly) and discretely--in the form of individual clouds of dust. Considerable polarization of the scattered light indicates the small (micron) dimensions

of the particles. As for the large rocks, it is not possible to determine their presence in the comet by optic methods of ground-based astronomy.

Academician G. I. Petrov and V. P. Stulov, in analyzing the details of the Tunguskiy catastrophe in 1908, assume that the comet nucleus could be a mainly icy, mechanically-linked structure with extremely low average density, on the order of  $10^{-2}$  g/cm<sup>3</sup> [5].

Lyttleton criticizes and completely rejects the model of the comet nucleus made of "contaminated ice" and assumes, that in fact this must be an enormous cluster with diameter of  $10^7$  km made of particles  $10^{-2}$  cm in size that are not inter-linked [6].

We see, that in order to solve a number of questions on the nature of comets /6 additional, new information is required that can only be obtained from observations from a close distance. Probably, the only effective means, as in the case of studying planets, would be the use of rocket space equipment, that is capable not only of bringing the optic instruments close to the objects, but also of guaranteeing the possibility of direct probing with the use of physical instruments.

At the first stage it is required to make a preliminary space experiment in order to obtain information that is primarily necessary to evaluate the danger of bringing the space vehicle close to the nucleus of the comet in certain limits, and passing through the stream of substance in the comet tail in the environs of the nucleus. To navigate the space vehicle during the approach to the comet head on-board photographs of the comet nucleus on the background of the stellar sky could be used that can be attained by stabilized platform.



The question of the desirable composition of the scientific apparatus for the comet probe has been examined exhaustively in a number of foreign publications [7, 8, 9].

The first successful flight of a space probe to one of the comets promises to be productive in relation to scientific discoveries.

#### Selection of a Comet for Study with the Help of a Space Probe

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Variations of the same characteristics in different comets, as is known, are very great. In addition, the comets strongly differ in their accessibility, first of all, in the sense of the ballistic potentialities of converging with the nucleus, and flying through the ball with a moderate, relative velocity. Comets are preferable that are rotating on circumsolar orbit in the same direction as the Earth, and that have an orbital plane that is close to the plane of the ecliptic and perihelion distance from the sun in the limits from 0.3 to 1.2-1.5 a. u. Beyond the limits of this range towards one side--in the environs adjacent to the sun with radius 0.3 a. u.--the extremely high level of insolation complicates the requirements for the system of thermoregulation and the materials for making the scientific apparatus and technical systems on the space vehicle; towards the other side of this range--with a great distance of the comet from the sun--the activity of the comet nucleus (main subject of studies) is displayed weakly.

All of these circumstances are at the basis for selecting a comet to be visited by a space vehicle, but this selection, unfortunately, is extremely limited. We will turn to the catalog of comet orbits [10]. Of the only 63 predictable comets that have been observed in no less than two passages in the region of the perihelion, only very few satisfy the necessary requirements, if one bears in mind that only

those comets whose periods of subsequent rotation in the environs of the Earth group planets will fall no further than in the two immediate decades. The requirements listed above are satisfied by the objects listed in Table 1, which includes comets with incline up to  $32^\circ$ .

If one is restricted to incline in limits of  $15^\circ$ , and excludes from the table those comets that even at a close distance from the sun remain very weak, then almost nothing remains of the selection. In addition one could take into consideration those periodic comets that were observed only in one passage, and must return to the perihelion in immediate years; but the liability of predicting the return of such objects is insufficiently high in many cases. Probably, therefore the published projects are restricted to an examination of the flight variance of comets that are observed many times. /8

The United States has developed projects for a flight to the comet Encke-Baklund [7, 8, 13], as well as to the famous Halley's comet [9], which has not been included in our Table 1, since the incline of the orbital plane of Halley's comet is  $162^\circ$ . In other words, it moves comparatively close to the orbital plane of the earth, but in the opposite direction, which strongly complicates the flight ballistics to this comet of a space probe by significantly increasing the necessary launching power and duration of the flight. In order to reduce the impulse necessary for putting the space vehicle into orbit with reverse motion, it has been suggested that the space vehicle be preliminarily put into an intermediate orbit of direct movement with aphelion at a heliocentric distance of about 4.5 a. u. [14]. Nevertheless, Halley's comet is considered to be worth special attention due to its physical characteristics that approach the characteristics of the most prominent comet.

TABLE 1. BALLISTICALLY-ACCESSIBLE KNOWN PERIODIC COMETS

Comets	Incline, deg.	Perihelion, a. u.	Period, Years	Year of Discovery	Absolute Brightness*	Dates of Perihelion
Reinmuth I	8.29	1.995	7.63	1928	12-14	1980 XI, (1988 VI)
Encke	11.97	0.339	3.30	1786	12-14	1980 XII, 1984 III, (1987 VII), (1990 X)
Schaumass (?)**	12.02	1.196	8.18	1911	Weak	(1984 XI), (1993 I)
Temple 2	12.48	1.364	5.26	1873	9-13	1983 V, (1988 VIII)
Honda-Mrkos- Peaydushakova	13.13	0.579	5.28	1948	Weaker than 14	1980 IV, 1985 VII
D'Arrest	16.68	1.167	6.23	1851	9-10	1982 XI, (1989 I)
Brorzen-Metkol'f	19.22	0.484	71.9	1847	9-10	1991 IX
Grigg-Skjellerup	21.07	1.001	5.12	1902	Weaker than 14	1982 V, 1987 VII
Pons-Winnecke	22.32	1.247	6.34	1819	Weaker than 14	1983 III, (1989 VII)
Borrelly	30.22	1.316	12.65	1905	11-13	1987 I, (1999 VIII)
Giacobini-Tsinner	31.71	0.994	6.52	1900	12	1985 VIII
Ashbrook-Jackson	12.53	2.285	7.43	1948	6-8	
					Extrapolation 1986 I	

\*The stellar magnitude of the comet during subsequent appearances relative to the distance 1 a. u. from the sun and from the earth according to [11, 12].

\*\*In 1968 and 1976 the comet was not observed, despite the timely publication of the ephemeris with regard for disturbances from all the planets according to the initial orbital elements of 1960.

What is preferable: selection of a comet with regard for the conditions of ballistic optimality formulated above, or flight to a comet that is brighter than the comet Encke, but with outlays of considerably greater resources for implementation of the program?

It is possible to eliminate the alternativeness of the selection and to satisfy all desires without a perceptible increase in the cost of the program, if one radically alters the approach to the question and focuses attention on the third path. /9

The extremely limited selection of the comets to which a space probe could be launched is due to the fact that objects are examined only from the number of known periodic comets with predicted imminent return to the perihelion. At the same time there are considerably more unpredictable comets. Their orbits in the overwhelming majority of cases are extremely elongated ellipses with large semiaxis from tens of astronomical units and more. The magnitude of distance from the sun in the perihelion for these comets has a broad spectrum of distribution, while the incline of the orbital plane to the ecliptic does not have restrictions.

Any previously unknown comet that is found at the inlet branch of its orbit invariably passes through the perihelion; only a certain period is required for observation of its movement, in order to pinpoint the parameters of movement and to guarantee the obtaining of a fairly accurate ephemeris. In those cases where the orbital elements satisfy the assigned requirements of ballistic accessibility, with a fairly early detection of the comet one can send a guard space vehicle prepared for this purpose to "intercept" it from the first orbit on a trajectory that guarantees the slowest possible velocity of the space vehicle in relation to the comet nucleus on the section of close convergence.

The task of early detection of comets is a labor-intensive task, but it can be fulfilled at the price of expending the necessary efforts and comparatively small resources. This question is discussed in the concluding section of this article. Its positive solution not only would guarantee the fulfillment of the proposed strategy, but also would permit associated priority results to be obtained: the number of discoveries of asteroids, supernovas, and new stars, etc. /10 would increase.

Thus, it is recommended that attention be focused on the possibility of conducting direct probing of one of the newly-discovered comets. Objects are encountered among them that have violent activity of the nucleus that is manifest under the influence of solar radiation; in addition, their appearance occurs several times more often than the known periodic comets. Consideration of these circumstances provides the grounds to assume that studies with space vehicles of newly-discovered comets are fairly promising.

#### Time Supply Before Blast-Off of the Space Vehicle and Velocity of Rendezvous with the Comet

We will examine as a preliminary study the possibility of rendezvous between a space vehicle and comet on the detection orbit. A flyby variant is implied.

To evaluate the basic possibility of realizing a flight to a newly discovered comet it is important to clarify what the time supply is from the moment a comet is detected to the blast-off of the intercepting rocket. The figure presents results in examination of this question. Four curves resembling a family of parabolas depict the segments of the computed long-periodic comet orbits with distance of the sun in the perihelion 0.3, 0.6, 0.9 and 1.2 a. u. The calculation of the motion velocity assumed the large semiaxis of the ellipses for concreteness to be

equal to 100 a. u., based on the fact that the values for the comet velocity and shape of the orbit are altered little during changes of the large semiaxis in the limits  $30 < a < 10^5$  a. u. Since in the rendezvous task we are interested only in comets with small incline of the orbit, in the first approximation we consider that they move in the plane of the ecliptic.

As a route for the space vehicle flight from blast-off from the earth, or from the orbit of an AES [artificial earth satellite] to rendezvous with the comet we preliminarily adopt in all four variants mono-elliptical 180-degrees\* orbits (depicted by dotted line), tangential to the comet orbit at the points of the perihelion. This determines the duration of the flight, indicated next to the rendezvous point in units of solar days. The system of segments that intercept the comet orbits in Figure 1 represent isochrones, that indicate the moment of comet passage through the corresponding points of their orbit; the moments are indicated by the number of days that remain to the blast-off of the intercepting rocket. /12

The duration of flight from the zero isochrone to the perihelion corresponds to the readings next to the rendezvous point. The concentric circles and curves show the orbit of the planets and the scale of distances from the sun (in astronomical units).

Calculation of the orbital movement of comets and the space vehicle were made according to the following plan (the system of employed designations given below corresponds to the generally accepted).

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\*With a considerable incline of the orbital plane of the comet a flight on another plan is more efficient, with blast-off in the environs of the point of intersection by the planes of the earth and comet orbits.

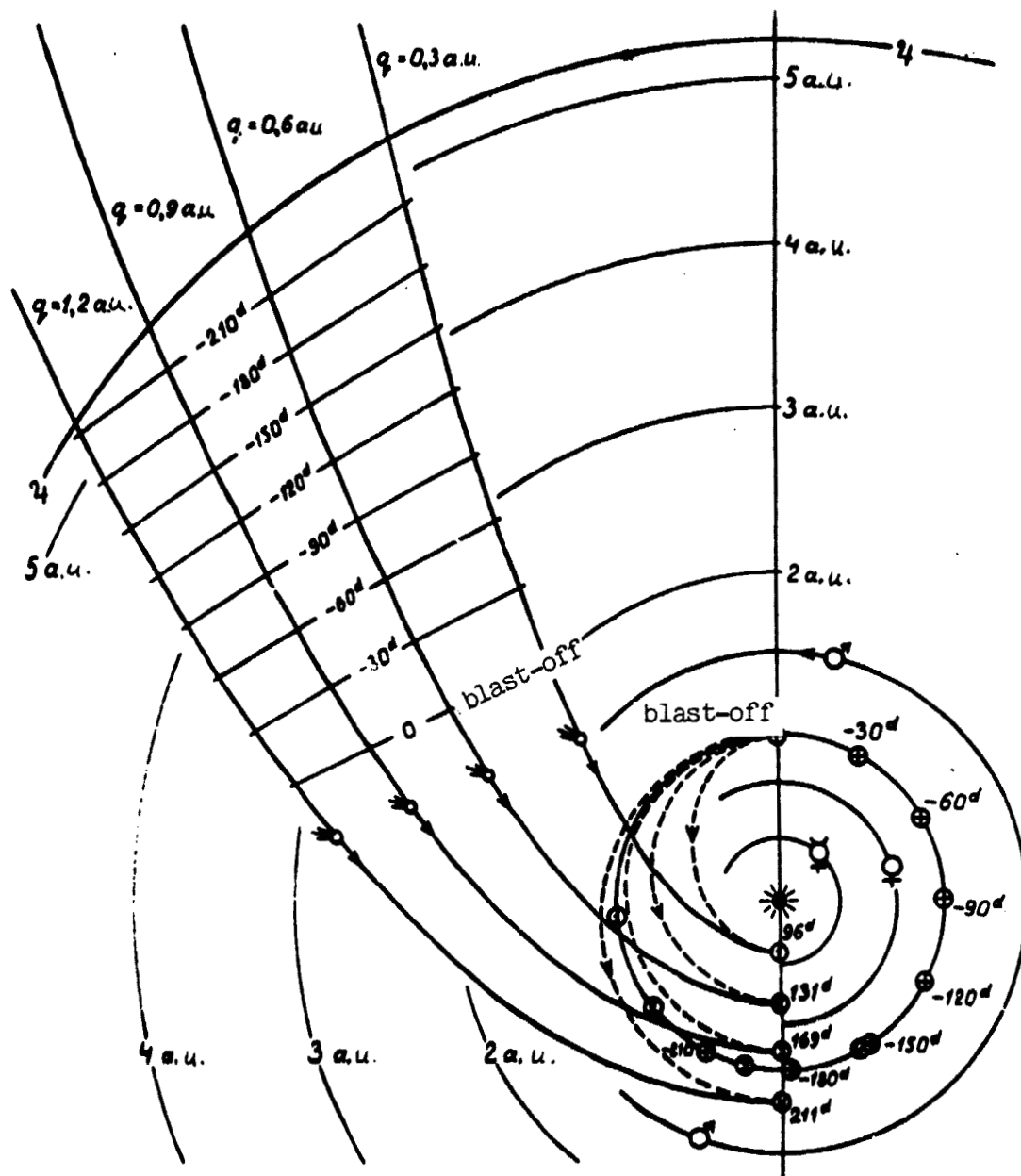


Figure 1. Estimates of the Time Supply the Moment a Newly-Discovered Comet is Detected to the Blast-off of the Intercepting Rocket in a Preliminary Flight Plan According to a Semi-Elliptical 180° Trajectory, Tangential to the Comet Orbit in the Perihelion. Explanations in text.

The line of the orbit was computed according to the formula

$$r(v) = \frac{q(1+e)}{1 + e \cos v}, \text{ where } e = 1 - \frac{q}{a};$$

control:  $r(v = 90^\circ) \approx 2q$ .

The duration for passage of orbital sections in arbitrarily selected intervals  $v-v_0$  was computed in the following sequence of operations: we find E from

$$\sin E = \frac{r \sin v}{a \sqrt{1-e^2}};$$

control:  $r(E = \frac{\pi}{2}) = a$ ;

further we obtain M by using the Kepler equation  $M = E - e \sin E$ ;

finally, from the average movement n we compute  $t(v) = \frac{M}{n}$ ; /13

control: with  $v \rightarrow 180^\circ$ ,  $t \rightarrow P/2$ .

The periods of orbital movement are determined for the argument a by the third law of Kepler.

The following designations were used above:

$r$  - heliocentric radius-vector

$v$  - true anomaly (heliocentric angle from perihelion),

$q$  - perihelion distance from sun,

$e$  - eccentricity,



$a$  - large semiaxis of elliptical orbit,

$E$  - eccentric anomaly,

$M$  - average anomaly,

$P$  - period of rotation,

$n$  - average movement,

$t$  - duration of movement, up to perihelion ( $v_0$ ) from the orbital point corresponding to the heliocentric angle  $v$ .

The velocity of the comet and the space vehicle on the rendezvous section is found from the formula

$$V = \sqrt{\mu M \left( \frac{2}{r} - \frac{1}{a} \right)}, \quad \text{where } \mu M \text{ is the heliocentric}$$

gravity parameter equal to the product of the gravity constant (square of the Gaussian gravity constant) times the weight of the sun.

We find that the velocity of the space vehicle in relation to the comet nucleus on the rendezvous sections is 9.3 km/s, 11.2 km/s, 11.9 km/s and 12/3 km/s in the four orbital variants examined here. With such velocities one can only speak of a flyby rendezvous variant. But we are primarily interested in the entire supply of time from the moment the comet is discovered to the blast-off of the intercepting rocket in any applicable flight variant.

From the time layout in Figure 1 it is easy to see that from the moment the comet enters the limits of the sphere of possible detection (whose radius is more than 5 a. u.) until it approaches the perihelion a considerable time interval occurs, /14 more than a year, and before the blast-off of the interceptor—7-8 months.

### What is Required for Early Detection of Comets

One can show that for any constellation in an arbitrarily selected section of the celestial sphere during the year a period invariably occurs that is favorable for observation from astronomical observatories, at least from one of the earth's hemispheres (northern or southern). Nevertheless, astronomers do not always find comets fairly rapidly after their appearance. This becomes evident in the example of the extraordinary cases recalled from V. G. Fesenkov [3]:

"During the complete solar eclipse of 6 November 1948, suddenly a fairly bright comet appeared for the observers around the sun. In a like manner, the large comet Mrkos was found in 1957 only when it was already distant from the sun, before that it remained unnoticed."

One could name numerous cases where a certain comet was found only after it approached a distance of 2 a. u. or less, after which it passed through the perihelion, and becoming distant, remained accessible for observations all the way to distance 5 a. u. from the sun. Certain departing comets were observed at a distance of over 10 a. u.! This makes it possible to judge the brightness of the comet on the inlet branch of the orbit, and confirms the possibility of considerably earlier detection. Detection is possible from telescopic photographs of the stellar sky, on which the comets all the way to a distance of at least 5 a. u. from the sun are recorded as sufficiently characteristic diffuse objects that differ from the nebulae of a different nature. Besides morphological features, a noticeable movement detected by comparing two or more negatives is inherent to comets. The comparison method facilitates the search for objects with noticeable natural movement on the background of numerous practically immobile objects. /15

The special service of early detection of comets can be set up on the basis of the astronomical observatories and instruments active in the USSR: wide-angle astrographs of very modest dimensions are necessary ( $D \approx 40$  cm) that are located in low-latitude points with a large number of bright nights, and a well centralized organization of observations.

Photographic observations of the stellar sky on wide-angle astrographs guarantee excellent accuracy of the comet coordinate measurement to compute the elements of its orbit, but at the searching stage it is necessary to patrol sections of the sky of considerable area, that is, very long and regular use simultaneously of several instruments (from those available, or those that can be especially bought for this purpose), as well as the regular participation of the necessary personnel in order to obtain the numerous photographs with time exposures, subsequent immediate laboratory processing, and rapid and thorough examination.

In the work of the astrophysical instruments, as a rule, overloaded by the fulfillment of a number of programs, every month there is a forced interval, ten days of light sky near the full moon, and in the rest of the time observations are often interrupted due to unfavorable meteorological conditions. This somewhat reduces the reliability, but does not decrease the importance of using astrophotography to search for comets.

A more reliable additional method (but, in the rapidly realizable variant, less "long-range" and requiring a large output of labor and time) of early detection of comets and preliminary determination of their coordinates could be the extra-atmospheric observations. Not to mention their independence of meteorological conditions, observations from an orbital station are the only possibility for viewing sections of the stellar sky at small angular distances from the sun (located not

very far below the horizon) and the only possibility for searching for comets in the period of the bright moon, when the ground-based observations are impossible as a consequence of the intensive illuminating of the earth's atmosphere by the moon, which shines almost the entire night: several nights before the full moon it sets before dawn, and the sky barely succeeds in becoming dark, and on the 15th-18th day of the lunar phases—it rises after the evening twilight. For fairly accurate position observations of the comet the use of an orbital astrograph on a stabilized platform would be ideal, but since it is lacking one can be limited to the use on a manned station of a light, visual comet finder that is suitable as a means of preliminary target indication of the ground surface that possesses the stationary apparatus. We will briefly discuss the selection of the comet finder plan. It is known, that to search for converging comets located a distance of more than 2 a. u. from the sun, the standard visual methods of observations are not very effective, and consequently, are inapplicable in our task. But the author of this article, based on personal experience of observation of galaxies and planetary nebulae using image brightness amplifiers assumes that under the conditions of a dark sky visual detection of weak diffuse objects of low surface brightness is possible by slow scanning of the sky in optic instruments, equipped with brightness amplifiers with a large field of good image. Of course, the observer must have a good knowledge of the stellar sky, and have practical experience of observation in order to distinguish the comet from other diffuse objects. One should bear in mind here, that in the spectrum of comets at a great distance from the sun there are no characteristic emissions, there are only continuums [15].

In order to increase the efficiency of any service that is searching for comets /17 suitable for "interception," one can indicate sections of the sky that the comet

cannot avoid, that are approaching us on orbits with parameters in the necessary limits. These sections of the sky are located in a band along the ecliptic and adjoin the sectors of the evening and morning redness. The width of the search band is determined by the distance of the comet from the plane of the ecliptic. The heliocentric angle of this distance is contained in the limits  $i \angle d \angle i$ , where  $i$  is the inclination of the comet orbit plane. The corresponding geocentric angle is smaller than the heliocentric, if the comet is farther from the earth than from the sun, and it is easy to see from the drawing (Figure 1) that such a condition is not violated in the limits of periods of 210-60 days before the blast-off of the intercepting rocket. That is, all the approaching comets with inclination  $i$  of the orbital plane should be sought for on sections of the evening and predawn sky in the belt  $\pm i$  from the ecliptic. On the evening section, in the range  $40-80^\circ$  from the sun, it is necessary to provide distance of detection at distance 4-5 a. u., and on the morning section--in the range  $30-70^\circ$  from the sun--at a distance 2.5-3.5 a. u. The conditions for detection of subsequent observation from earth of comets that are suitable for "interception" are characterized by data given in Tables 2a, b. The technique of searching is reduced to patrolling the indicated sky sections.

In examining the strategy for selecting comets for space programs, apparently, one should not exaggerate the advantages of flying to one of the well-known periodic comets as compared to the "interception" of a newly discovered comet suggested here, since significant refinements in the orbit before the blast-off of the space vehicle, and corrections during flight are inevitable also in the case of any known periodic comet. It is known that by expecting return of the comet to the sun with previously measured orbital components, one cannot be positive that these elements were preserved unchanged from the previous orbit. The comet orbits are altered at

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TABLE 2 (a) and (b). OBSERVATION CONDITIONS FROM EARTH OF COMETS IN ORBITS THAT SATISFY WITH  $\alpha > 30$  THE CONDITIONS OF BALLISTIC ACCESSIBILITY WITH DIFFERENT VARIANTS OF THE PERIHELION.

(a) Angular distance (degrees) of comet from sun and indication of the morning or evening visibility.

Time (days) from the Moment of Blast-Off According to the Plan in Figure 1	$q=0.3$ a. u.	$q=0.6$ a. u.	$q=0.9$ a. u.	$q=1.2$ a. u.
- 210	47, even.	57, even.	66, even.	73, even.
- 180	22, even.	32, even.	40, even.	47, even.
- 150	(1, morn.)	9, even.	16, even.	23, even.
- 120	23, morn.	12, morn.	5, morn.	(1, even.)
- 90	44, morn.	34, morn.	26, morn.	21, morn.
- 60	65, morn.	54, morn.	47, morn.	41, morn.
- 30	87, morn.	75, morn.	69, morn.	64, morn.
0	107, morn.	94, morn.	88, morn.	84, morn.
At perihelion	16, morn.	37, morn.	60, morn.	95, even.

TABLE 2 (b) LINEAR DISTANCE (a. u.) OF THE COMET FROM THE SUN AND FROM THE EARTH

Time (day) from the Moment of Blast-Off According to the Plan in Figure 1	$q = 0,3$		$q = 0,6$		$q = 0,9$		$q = 1,2$	
	⊙	⊕	⊙	⊕	⊙	⊕	⊙	⊕
- 210	4,85	5,47	4,86	5,32	4,98	5,28	5,20	5,36
- 180	4,46	5,38	4,54	5,35	4,68	5,39	4,90	5,54
- 150	4,08	5,08	4,20	5,20	4,38	5,34	4,62	5,54
- 120	3,70	4,62	3,86	4,86	4,06	5,07	4,34	5,36
- 90	3,30	3,94	3,50	4,26	3,74	4,62	4,04	4,96
- 60	2,90	3,18	3,12	3,62	3,42	4,04	3,74	4,44
- 30	2,48	2,34	2,74	2,84	3,10	3,32	3,42	3,76
0	2,02	1,48	2,32	2,02	2,72	2,54	3,10	3,02
In the perihelion	0,30	1,03	0,60	0,78	0,90	0,25	1,20	0,57

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from large planets. Such disturbances can be predicted, which is done in each period of revolution of the comet. But nongravity effects are also observed. The previous interpretation of reduction in the period of revolution of the comet Encke linked to the hypothesis on the considerable resistance of the interplanetary medium, was groundless after the detection of the opposite effect, the increase in energy of movement and dimensions of the orbit of the comet Brooks. Nongravity changes in the orbit that are characteristic for many comets occur, according to modern ideas, as the result of the effect of jet forces during intensive prolonged or/and violent discrete emissions of considerable weight of gases and dust from the comet nucleus under the influence of heating by solar rays during passage in the environs of the perihelion. The direction of effect of the summary impulse is determined by parameters of the axial rotation of the comet nucleus in accordance with the formulas indicated in publication [3]. The effect would have a systematic nature in the case of a repeating dependence of the rate of emission of the material on the intensity of radiation, but in fact the smoothness and reproducibility of this dependence are not confirmed by observations. The intensity of emissions in two successive passages of the comet to the perihelion can differ several times, by altering the magnitude of the summary impulse. The discrete emissions evidently affect both the magnitude and the direction of the summary impulse, by introducing chaotic fluctuations.

Since the weight of the escaping material is small as compared to the weight of the comet nucleus, the nongravity effects are small as compared to the gravity, nevertheless they are recorded. Astronomical scales of distances and velocities, apparently require their rapid consideration in the task of a rendezvous between /15  
the space vehicle and the comet in any flight variant.



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#### References

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1. Levin, B. Yu. "Origin of Comets," Voprosy kosmogonii, 9 (1963), 215-231.
2. Bailey, M. E. "Some Comments on the Oort Cloud," Astrophysics and Space Science, 50, No 1, 3-22, 1977.
3. Fesenkova, V. G. "Origin of Comets," Astron. zhurn., 28 (2), 1951, 98-11.  
"Nature and Origin of Comets," Astron. zhurn., 39 (4), 1962, 583-590. Izbrannyye trudy. Solntse i solnechnaya sistema ["Selected Works. Sun and Solar System"], Moscow, Nauka, 1976.
4. Bertaud, Ch. "Les Cometes de l'annee 1975," Astronomie, 91, 281-292, 1977.
5. Petrov, G. I.; and Stulov, V. P. "Movement of Large Bodies in Planetary Atmospheres," Kosmicheskiye issledovaniya, 13 (4), 1975, 587-594.
6. Lyttleton, R. A. "What is a Cometary Nucleus?" Quart. J. Roy. Astron. Soc., 18, No 2, 213-233, 1977.
7. Nock, K. T.; and Yeates, C. M. "Early Mariner Comet Flyby," AIAA Pap., No 198, 8 pp, 1975.
8. Duxbury, J. H.; and Paul, G. M. "Interplanetary Spacecraft Design Using Solar Electric Propulsion," AIAA Pap., No 1084, 12 pp, 1974.
9. A First Comet Mission. Report of the Comet Halley Science Working Group, NASA, TM-78420, 1977.
10. Marsden, B. G. Catalogue of Cometary Orbits, 2nd ed. Cambridge, USA, 1975.
11. Vsekhsvyatskiy, S. K. Fizicheskiye kharakteristiki komet ["Physical Characteristics of Comets"], Fizmatgiz, Moscow, 1958.
12. Vsekhsvyatskiy, S. K.; and Il'chishina, N. I. Fizicheskiye kharakteristiki komet ["Physical Characteristics of Comets 1965-1970"], Fizmatgiz, Moscow, Nauka, 1974.

13. Jaffe, L. D. et al., "Imaging on Ballistic Missions to Comet Encke," AIAA Pap., No 87, 14 pp, 1975.
14. Hughes, D. W. "Visiting Halley's Comet," Nature, 268, No 5620, 486-488, 1977.
15. Bertram, D. The Characteristics of Distant Comets, Washington, 1963.